Radio-Frequency Radiation Safety and Health

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Current Standards and Their Bases for Safe Human Exposure to Radio-Frequency Radiation

The scenario of a persistent, publicly expressed lack of confidence in radio-frequency (RF) exposure standards pertaining to the maximum permissible exposure (MPE) level of humans exposed to RF electromagnetic radiation has been playing in many parts around the world of wireless telecommunications. Several national and international organizations are engaged in examining existing guidelines or maximum permissible exposures for humans. Each of these efforts has convened groups of interested parties to deliberate on the reasons and to decide on guidelines to deem exposure as safe, and, hopefully, to make explicit the philosophy and procedure invoked in the decision-making process.

Exposure guidelines for RF radiation have been promulgated for nearly half a century. However, our understanding of the biological effects of exposure to RF radiation is still evolving, and more so for cellular mobile telephones and wireless personal communication devices. It is expected – and mandated by some of the standards setting bodies – that any exposure criteria set forth should be evaluated periodically, and possibly revised as new information becomes available from continuing research on the subject. Likewise, rationales for the exposure criteria must be reassessed in view of new laboratory findings and human health studies.

There are two principal sets of guidelines promulgated for limiting human exposure to RF radiation worldwide. Much of the current effort is driven by the advent of cellular mobile telephony, which uses radio-frequency (RF) radiation in the range of 800 to 2500 MHz. In response, a standard was adopted by the US Federal Communications Commission (FCC) for protection against any effects of RF radiation in August, 1996 [1]. Likewise, guidelines for limiting human exposure to RF radiation from cellular mobile telephone operations have been adopted around the globe. For example, the maximum power deposition (measured in specific absorption rate of RF energy, or SAR) allowed varies between 1.6 W/kg in 1 g and 2 W/kg in any 10 g of tissue in the head, for exposure to cellular telephone wireless radiation. However, the popularity and ubiquity of cellular mobile telephones have posed new questions regarding the adequacy of the existing knowledge of biological effects of RF electromagnetic fields and of the protection afforded the public from any harmful effects of these fields.

In fact, the numbers used for the guidelines are not new, in that they were derived from then-existing (and currently promulgated) exposure guidelines for RF radiation. There is the sense that a cellular mobile telephone, putting a radiating RF source next to the user's head, is a new phenomenon that has no precedence. There has been palpable concern about the adequacy of existing scientific knowledge and uncertainties, even among the users. It is of interest to examine the scientific basis used for establishing these exposure guidelines. (For this discussion, we will not address the well-known differences among the RF guidelines promulgated for limiting human exposure in countries like Russia and the former Soviet Union. It should be noted that a draft of the amended exposure standard in China appears to have recommendations that differ from both ANSI/IEEE and CENELEC/ICNIRP guidelines.)

The use of the dosimetric quantity SAR was initiated as a recommendation of the National Council of Radiation Protection and Measurements (NCRP) [2]. This unit-mass, time-averaged rate of RF energy absorption was adopted by the American National Standards Institute (ANSI) in 1982 [3]. The limit of 1.6 W/kg in one gram of body tissue for the general public or the uncontrolled environment was recommended by the IEEE in 1992 [4]. (Note that since 1990, the development and revision of the ANSI standards

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have came under the sponsorship of the IEEE Standards Association.). The latter had followed considerations by NCRP that – for exposure criteria based on whole-body-averaged SAR – a number of studies have demonstrated that the maximum SAR in small regions inside the body may be as much as 10 to 20 times higher [5].

The ANSI/IEEE standard relied on the careful interpretation of a list of papers selected from the peer-reviewed literature that were deemed to have biological, engineering, and scientific validity. In the frequency region of interest (100 kHz to 6 GHz), a SAR value of 4 W/kg, temporally and spatially averaged over the whole body mass, was adopted as the working threshold for adverse biological effects in humans. Above this threshold, disruption of work schedules in trained rodents and primates, and other adverse biological effects, have been demonstrated. Moreover, it was noted that a metabolic heat-production rate of 4 W/kg falls well within the normal range of human thermoregulatory capacity. Recognizing that there are scientific uncertainties and also biological variability in the human population, a safety margin of 50 was incorporated into the standard, to limit exposure of the general population to 0.08 W/kg in one gram of tissue, as averaged over the entire body, for periods of 15 to 30 minutes. Clearly, the ANSI/IEEE C95.1-1992 Standard provides recommendations to prevent adverse thermal effects on the functioning of the human body, although the assessment criteria for reports of biological effects were without regard to mechanisms of interaction.

Since for a given exposure the SAR distribution inside the human body varies from point to point, a partial-body limit was recognized for all parts of the body. It was generally accepted then that the maximum localized SAR could be as high as 20 times the whole-body-averaged SAR. Therefore, for localized exposures of smaller regions in the human body, a relaxation of the maximum permissible exposure limit to 1.6 W/kg in any 1 gram of tissue was introduced for partial-body exposures.

Studies using animals in the near field have shown that the minimum cataractogenic SAR (the minimum SAR required to produce a lens cataract) is about 100 to 150 W/kg for up to 100 minutes in the vitreous body of the eye [6]. Moreover, available numerical and experimental investigations indicated that a retrolental temperature (the temperature behind the lens) of 41°C was necessary for production of posterior lens opacities in rabbits. The temperature rise was induced by a peak SAR in the eye that occurred right behind the lens for the exposure conditions investigated (2450 MHz in rabbits). If the retrolental temperature was kept from exceeding 41°C by means of whole-body hypothermia, potentially cataractogenic microwave exposure did not produce any opacity in the lenses of exposed animals. These findings supported the notion of a thermal mechanism for microwave cataractogenesis.

Indeed, the sensitivity of the visual organ to RF electromagnetic energy-induced heat formed the basis for CENELEC in its effort to promulgate the limit of 2 W/kg averaged over 10 g of tissue for partial-body exposures [7]. Clearly, the motivation was to limit temperature rises inside the eye to prevent formation of lens opacity: cataracts. Specifically, a safety factor of 10 was applied to reduce the SAR threshold of 100 W/kg to 10 W/kg. To provide for an additional margin of safety for the general public, an extra factor of five was introduced to arrive at 2 W/kg over 10 g of contiguous tissue, including the eye. This exposure limit is about 50 times below the SAR reported (inside the eye) for formation of lens cataracts. It became the accepted SAR safety limit in the head of a user for cellular mobile telephones in most European countries until 1999.

The European Union (EU) Health Council, with the support of the UK government agreed in 1999 on a recommendation for limiting exposure to RF electromagnetic fields, thereby establishing EU-wide safety standards for cellular mobile telephone emissions. The recommendation was based on the exposure limits recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), with its headquarters located near Munich, Germany.

In fact, the ICNIRP guidelines stipulate the same maximum SAR of 2 W/kg in any 10 g of tissue in the head and trunk up to 10 GHz over 6 minutes [8]. However, slightly different scientific bases appear to have been used in their development of the basic exposure restriction. While the restriction on SAR is intended to prevent excessive localized tissue heating, such as in the eyes and testes, considerations were given to SAR and tissue damage resulting from either partial-body or whole-body exposures that produce temperature rises on the order of 1°C in humans and laboratory animals. But the ICNIRP document did not clearly articulate the biological endpoint(s) upon which the rationale was drawn in supporting its choice of localized SAR values for the head and trunk. The guidelines were presented with the simple explanation of a desire to prevent excessive localized tissue heating. Thus, for all intents and purposes, the ICNIRP guidelines are essentially the same as the European (CENELEC) Pre-standard for partial body exposure.

It is worthy of note that – aside from the quantitative difference between the exposure standards (1.6 or 2 W/kg) – the tissue mass used to define the SARs in these standards (1 g for 1.6 W/kg or 10 g for 2 W/kg) can have a profound influence on the actual quantity of microwave energy allowed to be deposited in tissue by these exposure standards. It is well known that the distribution of absorbed microwave energy varies greatly from point to point inside a body, or inside the user's head from the RF radiation of a cellular telephone. An averaging volume that is as large as 10 g would tend to artificially smooth out the SAR distribution whether it is computed or measured. It also tends to lower

the numerical value of SAR by a factor of two or more. Thus, a 10 g SAR at 2 W/kg could be equivalent to 1 g SARs of 4 W/kg or higher. Simply put, the absorbed energy averaged over a defined tissue volume of 10 g is inherently low compared to a 1 g SAR.

The 1 g SAR is a more precise representation of localized microwave energy absorption, and a more biologically significant measure of SAR distribution inside the body or head. For example, the spherically-shaped human eye has a total mass of about 10 g. The use of an averaging volume as large as 10 g does not recognize any distinctions among tissues in the eye, and completely ignores the wide variation of SAR distribution throughout the eyeball. Also, it diminishes the safety margin of the 2 W/kg level in the eye. Likewise, the pinna or external ear has a mass that averages a little over 10 g. The adoption of 2 W/kg over 10 g of contiguous tissue grossly neglects the anatomic details of the ear and the nonuniform SAR distribution in the pinna. It could permit the deposition of RF energy in different parts of the pinna that exceeds the maximally permissible SAR by a large margin, while keeping the SAR for the entire pinna below 2 W/kg. Moreover, inside the human brain, the types and populations of cells and neurons are notably different, even in 1 g of tissue. There may be millions more cells, neurons, and aggregates impacted in a 10 g volume as compared to a 1 g averaging volume.

The quantitative values of SAR may be obtained by a detailed numerical computation, or from direct experimental measurements. The accuracy and reliability of computed results are sensitive to the models used to represent the user-handset combination, and to the parameters assumed for the head or user. Present computational schemes and resources can provide accurate induced electric field values with a spatial resolution on the order of a 1 mm in dimensions. The sensitivity and resolution of measurement instruments – such as implantable electric field probes or temperature sensors – are slightly larger, but of the same order of magnitude (a few mm).

It is important to recall that SAR is a localized quantity, and its value varies from one tiny location to another. The utility, resolution, and sensitivity of a given SAR value depend on the averaging volume or mass. The larger the averaging volume or mass, the lower the resolution and sensitivity of SAR, and the less useful it is as a metric for quantifying localized exposure and biological response.

The setting of guidelines or standards for maximum permissible levels of exposure to RF and microwave radiation is a valid approach to managing the risk of such exposures. The existing guidelines, however, are based on results obtained from acute, short-term studies that are atypical of the RF exposures associated with the handsets of cellular mobile telephones. For the first time in human history, a source of RF radiation is located right next to the head of millions of cellular mobile telephone users. Biological effects following repeated, prolonged, or lifelong exposure to RF energy emitted by these low-power wireless telecommunication devices have been investigated only during the past few years. The existing scientific results are equivocal and arguable in many respects. Consequently, there remains a widespread public concern about the adequacy of existing guidelines in safeguarding the general population against the possible harm of RF radiation from cellular mobile telephones.

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